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HELICOPTER EXTERNAL VISION REQUIREMENTS AND VISUAL DISPLAY CHARACTERISTICS: A REPORT/BIBLIOGRAPHY

Steven Hale
Essex Corporation

October 1987
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A literature review was conducted to examine helicopter external vision requirements and related visual display characteristics. Several articles are summarized in annotated bibliography format. A subsequent discussion section addresses the information contained in those articles as well as relevant information contained in other documents. Suggestions are made for future research.

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Introduction

In an attempt to define research needs related to the visual requirements of future U.S. Army aircraft, Essex Corporation, tasked by the U.S. Army Human Engineering Laboratory, has conducted a review of selected literature pertaining to helicopter external visibility and related visual display characteristics. Approximately 633 abstracts obtained through computer searches and 80 documents were reviewed. The result of this effort is presented here as a combination report/ bibliography. Several articles containing information most relevant to the topic area discussed here have been summarized in annotated bibliography format. Many articles have not been included because of the redundancy between the information they contain with the information summarized on the following pages. The various issues to be discussed include external vision requirements for rotary wing aircraft, helmet-mounted and panel-mounted display parameters, and physiological characteristics of the human visual system. The bibliography section will review, individually, those reports that experimentally examined some of these issues. The subsequent discussion section will discuss the information contained in those reports as well as information gained from a number of other documents.

Objective

The objective of this effort is to identify critical issues relating to aircraft external vision requirements and design specification considerations for visual display devices. Suggestions will be made for future research in areas lacking an adequate experimental data base.

Annotated Bibliography

Atkins, E. R., Dauber, R. L., & Price, J. W. (1973). Study to analytically derive external vision requirements for U.S. Army helicopters (Technical Report No. 73-1). St. Louis, MO: U.S. Army Aviation Systems Command.

This report presents an analysis of helicopter windshield external visibility requirements. The study objectives included (1) analytical derivation of external vision requirements for future and existing aircraft, (2) determining design trade-offs associated with incorporating the criteria derived from the study, and (3) the test and verification of the requirements. Among the aircraft included in the study were the OH-58 and the AH-1. The analysis methodology consisted of several steps: (1) develop theoretical visual baseline for man assuming head and eye movement only, (2) perform mission profile analyses for the various aircraft, (3) based on mission profile analyses, determine basic visual requirements (theoretical), (4) consider environmental and aircrew variables and, based on these considerations, modify the theoretical vision requirements, and (5) consider aircraft variables affecting visual requirements and accordingly modify the required visual envelopes to develop "real-world" window configurations.

To assist in the above methodology, the following types of data were gathered from both civilian and government agencies: engineering data (e.g., model specifications, fuselage contour data, crewstation geometry, external vision plots), operational data (e.g., operator's manuals, flight test reports, vision study reports), accident data, and pilot survey data. For each aircraft, the various phases of the mission profiles were categorized into terminal, cruise, mission, and contingency phases. Analyses of the specific missions performed during each phase resulted in the following recommended visual requirements for observation and attack aircraft (Tables 1 and 2).

Table 1

Recommended External Visual Envelope for Observation Helicopter

Azimuth	Elevation
0° to 105°	70° up
105° to 155°	decrease to 30° up
0° to 20°	30° down
20° to 30°	increase to 40° down
30°	increase to 60° down
30° to 120°	60° down
120° to 155°	decrease to 5° down

The above requirements assume a two-man crew seated side-by-side. These data are meant to represent the minimum angles of unimpaired vision available from the Design Eye Point (DEP) of either crewstation, viewing from centerline of pilot to maximum azimuth outboard. There should be no vertical obstructions between 20° right and left of the longitudinal axis relative to the DEP. There should be no horizontal obstructions in the area extending 15° above and below the horizon from 0° to 155° azimuth.

Table 2

Recommended External Visual Envelope for Attack Helicopter

Azimuth	Elevation
0° to 105°	90° up
105° to 155°	decrease to 10° up
0° to 20°	30° down
20° to 45°	increase to 45° down
45° to 120°	50° down
120° to 155°	decrease to 5° down

These data assume a two-man crew seated in tandem. The pilot position may be either forward or aft. The above visual requirements should be the minimum angles of unimpaired vision from the DEP of either crewstation.

A second study was conducted to determine the minimum visual envelope requirements for the observation helicopter. Three windscreen masking configurations were used during 12 flights in an OH-6. Both windscreen usage data (obtained by means of a Nac Eye Mark Recorder) and subjective pilot comments were collected for the different masking conditions. The most restrictive masking condition limited forward vision to +10° and -13° and limited side vision to +10° and -20°. Though pilots complained that the most restrictive masking condition was unsatisfactory, the mission profile was successfully completed under all masking configurations. The maneuvers flown were representative of typical OH mission profiles. However, the conditions under which the test was conducted did not represent true-to-life situations (e.g., minimal traffic, level terrain, and ideal weather).

Frezell, T. L., Hofmann, M. A., & Oliver, R. E. (1973). Aviator visual performance in the UH-1H: Study 1 (Report No. 74-7). Ft. Rucker, AL: U.S. Army Aeromedical Research Laboratory.

This study investigated aviator visual performance in terms of the areas of the windscreen most often used while flying 21 different maneuvers under visual flight rule (VFR) conditions. The authors also

examined the amount of eye movement taking place during the maneuvers, and the amount of visual dwell time spent in the different windscreen areas.

Visual performance was measured by a Nac Eye Mark Recorder used with a video recording system. The aircraft was divided into 13 sectors of vision as illustrated in Table 3.

Four values were calculated for each sector: total visual usage time (seconds), percentage of total time, number of exits from each sector area, and total dwell time (total time/number of exits). The longest dwell time occurred in sector 3 while the largest number of transitions occurred in sector 1 (transitions between instruments and windscreen). Overall, sectors 1, 2, 3, and 4 accounted for 90.28 percent of the total time. When the sector inside the aircraft was omitted and only windscreen eye movement was considered, 55.8 percent of the transitions occurred in the horizontal direction while 44.2 percent of eye movements were in the vertical direction. Table 3 presents summary data for all sectors from all maneuvers combined.

Table 3

Summary Table of Percentage Total Time and
Dwell Time for UH-1H Windscreen Sectors

13	8	9	5	4	7
1.0%	30%	.30%	1.70%	10.20%	4.1%
1.26	1.04	.82	.61	1.0	1.56
	11	10	2	3	
	1.03%	1.12%	15.02%	32.8%	
	1.21	.80	1.24	1.99	

12	1	6
.27%	32.26%	30%
11.37	1.84	1.04

Sector 1 - inside aircraft
Sector 2,3 - lower windscreen (right half)
Sector 4,5 - upper windscreen (right half)
Sector 10,11 - lower windscreen (left half)
Sector 8,9 - upper windscreen (left half)
Sector 7 - right door window
Sector 13 - left door window
Sector 6 - right chin bubble
Sector 12 - left chin bubble

Gomer, F. E., & Bish, K. G. (1978). Evoked potential correlates of display image quality. Human Factors, 20(5), 589-596.

The major purpose of this study was to substantiate an objective psychophysiological means of measuring the effects of display quality on visual information processing. The authors examined the effects of horizontal resolution and shades of gray on the amplitude of the average steady-state evoked potential. Subjects were presented with a checkerboard pattern on a 525-line TV monitor. The patterns consisted of alternate light and dark squares, each square subtending 10 min visual arc. During presentation, the stimulus patterns underwent rapid reversals, i.e., the light and dark portions of the checkerboard exchanged positions. Steady-state evoked potentials (EP) were recorded with the use of an electroencephalogram.

The two independent variables were resolution level of the stimulus pattern and the number of gray shades. Resolution values were varied between 185, 305, and 955 TV lines and the number of shades of gray varied between 3, 5, and 7. Though gray shades were varied, the mean luminance of the display remained constant at 95 cd/m^2. Stimulus reversal rate was 10 per second.

An ANOVA performed on the EP amplitude data revealed highly significant main effects of both resolution and shades of gray. However, by comparing the amount of variance attributable to both factors, and by examining simple main effects, it was evident that resolution had a greater influence on EP amplitude than did shades of gray. The amplitude associated with the 955-line resolution was significantly greater than that associated with the 305-line resolution ($p < .01$), which in turn was significantly greater than that associated with the 185-line resolution. There was no significant difference in amplitude between 7 and 5 gray shades when pooled across resolution levels, though the amplitudes for both 7 and 5 gray shades were significantly greater than that obtained for 3 shades of gray ($p < .01$).

Johnson, N. A., & Foster, M. (1977). Pilotage navigation utilizing a night vision system (Report No. TM6-77). Aberdeen Proving Ground, MD: U.S. Army Human Engineering Laboratory.

This study presents data from an experiment aimed at determining how field of view (FOV) and display medium affect ability to navigate using a forward looking infrared (FLIR) system. Pilotage navigation was defined as "the ability to navigate by correlating geographic landmarks with a hand-held map" (p.3). The test aircraft was an AH-1 equipped with a turret-mounted FLIR system, helmet-mounted display, and panel-mounted display. The turret was slewable to 90° left and right and ±32° in elevation. Three FOVs were examined: 15°x20°, 30°x40°, and 45°x60°. Though the wide FOV optics were not slewable in elevation, performance data indicated that this did not cause a major problem, as compared to the other FOV conditions.

All data were collected during nap-of-the-earth (NOE) flight. The navigator occupied the rear seat, which was completely enclosed by a curtain. The experimental design incorporated three modes of viewing (naked eye, helmet-mounted display [HMD], panel-mounted display [PMD]), 3 FOVs, and 2 NOE courses. Conditions were counterbalanced. Navigation was performed solely by reference to the HMD, PMD, and hand-held map (except for naked eye baseline trials). The navigator's task was to identify each of 6 check-points and the release-point along each NOE course. Each check-point and release-point was scored as "achieved" if the navigator correctly identified them within 100 meters.

One performance parameter analyzed was time to complete the course, i.e., the time from arriving at the initial point to the time of arriving over the release point. An ANOVA indicated no significant differences between displays or FOVs. There was, however, a significant display x FOV interaction ($p < .06$). A Tukey test indicated a significant difference between narrow and wide FOVs for each display. For the narrow FOV, navigating by PMD took longer than with the HMD. For the wide FOV, the effect was reversed. Also, both display types resulted in longer course completion times than did navigating with the naked eye.

An error analysis was also conducted to indicate the likelihood of mission abort under each condition. Two measures were combined to form an overall error measure: complete disorientation (subject was lost) and help from the safety pilot (subject was lost but was unaware of it). An ANOVA was calculated for the total number of errors of this type for each flight condition. Results indicated a significant difference between the wide FOV and the other two FOVs ($p < .05$). There was no significant difference between the medium and narrow FOVs.

Finally, an analysis was conducted on the number of sensor slews actuated under each condition. Results indicated significant differences ($p < .001$) between display types and FOVs. The HMD was slewed considerably more than the PMD, and the narrower the FOV, the more slewing there was.

These data suggest that the wider (45°x60°) FOV was much more effective for NOE navigation. Even when utilizing the slewing capabilities extensively, the narrow (15°x20°) FOV did not provide enough information for successful task completion.

Keneally, W. J., Keane, W. P., & Milelli, R. V. (1972). Operational evaluation of HMD characteristics. Proceedings of a Symposium on Visually Coupled Systems: Development and Application (pp. 68-92). Brooks Air Force Base, TX: Aerospace Medical Division.

The results of two experiments evaluating HMD characteristics are reported. The first was performed in a moving base simulator--the Tactical Avionics Systems Simulator (TASS). The TASS is a large-scale simulation facility consisting of a dual hybrid computer complex integrated with TV/terrain models and an operable cockpit mounted on a four degrees of freedom motion system. Flight tests of the HMD system

were conducted aboard the Research Aircraft for Visual Environment (RAVE), a modified CH-53 equipped with a third pilot's station in the forward section of the fuselage. The subject pilot has a complete set of flight controls at this station from which all of the information required to fly the aircraft is provided by the HMD or PMD.

Both helmet-mounted and panel-mounted displays were evaluated. The display FOV was 38°x48°. A minification of 2.5 to 1 was used. The four maneuvers studied were unattended area landing, precision hover, bob-up, and sideways flight.

In all of the simulation maneuvers, two of the three pilots experienced disorientation with the HMD as a result of confusing head movements with aircraft movement.

An experiment using a PMD was conducted to examine FOV and magnification. When each variable was independently controlled, pilots preferred a 1 to 1 magnification and as large an FOV as possible. However, when forced to choose between the two, pilots were willing to sacrifice 1 to 1 magnification if FOV could be maintained at a maximum.

The RAVE, used for in-flight testing, was equipped with a chin-mounted turret capable of slewing +30° and -60° in elevation and ±75° in azimuth. The HMD consisted of a 40° diagonal FOV and selectable resolution (either 525 lines/frame or 839 lines/frame). In addition to those maneuvers examined in the simulation study, the enroute maneuvers of terrain avoidance and terrain following were investigated during flight.

The HMD system did not allow successful accomplishment of terrain avoidance, terrain following, bob-up maneuvers, or sideways flight. To a limited degree, the HMD system did provide the capability to accomplish precision hover and unattended area landing.

Lazo, J., & Breitmaier, W. A. (1980). <u>Human factors engineering support in the helicopter night vision system simulation test program</u> (Report No. 80172-60). Warminster, PA: Naval Air Development Center.

This document describes the results of a human factors analysis conducted at NADC in support of the Marine Corps Helicopter Night Vision System (HNVS) development program. The analysis examined several aspects of the night vision system and its operation including aircrew visual requirements, aircrew performance, workload, and HNVS display and control characteristics. Several of the references cited were not available for the completion of this bibliography and as a result, many of the methodological details contained in those articles were not available for summary. This synopsis will concentrate on the discussions of aircrew visual requirements and HNVS display and control characteristics.

In examining the aircrew visual information requirements, a detailed segment-by-segment analysis of the projected Marine helicopter assault mission was performed. The overall assault mission was divided into 6 segments and the environmental cues associated with the different types of

information required for mission segment completion were identified. Based on these analyses, a composite of the critical visual requirements for a night vision system was compiled. These data are presented in Table 4 below. The authors suggest that these requirements are the most restrictive ones and that further research should be conducted to specify precise minimum requirements.

Table 4

Visual Requirements for a Night Vision System

Mission Segment	Field of View	Field of Regard	Resolution
Takeoff and Rendezvous	60°	± 90°	2 to 4 mr
Enroute Navigation	30°	± 50°	2 to 4 mr
Threat Detection	60°	± 90°	2 to 4 mr
Terrain Avoidance	60°	± 90°	2 to 4 mr
LZ Assessment and Approach	60°	- 60°, + 90°	2 to 4 mr
Landing	60°	- 60°, + 90°	2 to 4 mr

The authors also reviewed some of the literature pertaining to requirements for FOV and sensor slew capabilities. They briefly review the results of Air Force radar testing for terrain avoidance flight (Boivin, Schmidt, and Balfe, 1973). The results of these tests indicated that the widest possible FOV is needed and a slew capability of ± 60° would be necessary for flight as low as 100 feet above ground level (AGL). An additional study performed by the Marine Corps (Jensen and Haugen, 1973) reported successful low-level flight using a 30°x60° FOV FLIR system. However, the 60° horizontal FOV resulted in .7 magnification which caused problems with distance judgments. The pilots suggested the implementation of multiple FOVs with one providing 1 to 1 imagery.

The results of a 1972 Army report on night formation flight (Wilkin, 1972) indicate that a non-slewable 40° FOV was unsatisfactory. Pilots were unable to make adequate range and range rate estimates using a binocular fiber optic night scope.

Martin Marietta Orlando Aerospace. (1981). Helicopter night vision system simulation evaluation: Phase III (Contract No. N62269-80-C-0346). Warminster, PA: Naval Air Development Center.

The objective of the evaluation reported here was to conduct a simulation program in order to gain human factors data relating to low-level Marine transport helicopter operations using night vision sensors. That portion of the study to be summarized here evaluated the effect of various FOVs on performance during approach and landing operations. Three FOV conditions were evaluated: wide FOV = 50°, narrow FOV = 25°, dual FOV = 50° and 25° under pilot control. Each FOV was examined in the context

of each of four landing zone difficulty levels. Level 4 landing zone (LZ) was equal to 4.5 rotor diameters or more, level 3 LZ was 3.5 to 4.4 rotor diameters, level 2 LZ was 2.5 to 3.4 rotor diameters, and level 1 LZ (the most difficult) was 2 to 2.4 rotor diameters.

Touchdown and Enroute Results: Though there were no statistically significant touchdown performance effects due to FOV or LZ, the wide and dual FOVs tended to result in better performance.

Smoothness of Approach and Landing. Altitude control was less variable using the wide FOV and was rather erratic with the narrow FOV. Speed was inconsistent during approaches using the narrow FOV. This may have been due to the smaller field causing misjudgments of LZ distance.

Crash Rates. The combination of difficulty level and FOV variations affected the rate of successful landing attempts. The narrow FOV produced the smallest percentage of landings (46 percent) per attempts in the medium sized LZ. The wide field and the small LZ resulted in 100 percent landings per attempts. Technically poor landings (as measured by pitch angle, rate of descent, and rearward drift) occurred most frequently with the narrow FOV followed by the dual and wide FOVs, respectively.

Though encouraged to use their dual FOV capability, pilots spent only 2.09 percent of their time using the narrow FOV during approaches to the small LZ. Even less time was spent using the small FOV during landings and takeoffs, regardless of LZ size.

The largest amount of sensor slewing occurred in the small LZ with the narrow FOV. This indicates the greater need to look around in order to overcome an insufficient amount of imagery presented by the small FOV.

Generally, pilots preferred the wide and dual FOVs over the narrow. The wide and dual fields resulted in very little subjective variability.

Martin, W. L., & Warner, D. A. (1985). The use of a virtual cockpit in a simulated helicopter attack mission (preliminary observations) (Report No. 85-301). Wright Patterson Air Force Base, OH: U.S. Air Force Aeromedical Research Laboratory.

This report summarizes the results of a preliminary experimental study that simulated a helicopter attack mission using the Visually Coupled Airborne Systems Simulator (VCASS). The VCASS is a simulation facility that provides the capability of presenting computer-generated imagery to each eye independently through the use of a helmet-mounted display. The instantaneous field of view (FOV) can be experimentally manipulated and the orientation of the oculars is measured by a head tracking system and controlled through head movements. Thus, the system simulates the performance of a slewable sensor. The purpose was to gather preliminary data on the effect of various FOVs on pilot's abilities to complete the mission. Four different FOVs were compared: 40° monocular, 40° binocular, 90° binocular, 120° binocular. Each pilot flew a series of 24 five-minute sorties. Subjective workload ratings (SWAT) were collected on

the tasks of following a command heading to an enemy tank while flying contour and/or nap of the earth (NOE), defending against and/or destroying ground threat systems, and contending with a Soviet MI-24 Hind helicopter by attacking or defending. Subjective questionnaire data were also collected by having the pilots rate the effects of the various FOVs on mission success.

The questionnaire data (Table 5) indicated a progressive increase in pilot ratings from the 40° monocular FOV to the 90° binocular FOV for various aspects of the mission. However, there was very little difference in ratings between the 90° binocular FOV and the 120° binocular FOV. This may suggest that increasing FOV beyond 90° will not significantly improve pilot performance. The questionnaire data are reproduced in the following table.

Table 5

Mean Pilot Ratings of Various Fields of View
for Different Mission Scenarios

	MEAN RATINGS			
	40° mono	40° binoc	90° binoc	120°binoc
Overall Mission	1.75	2.75	5.0	5.5
Piloting	2.25	3.75	5.7	6.0
Navigation	2.25	3.5	5.5	6.0
Target Acquisition	1.75	3.25	4.5	4.75
Weapon Delivery	2.75	3.75	5.25	5.0
Survivability	1.5	2.5	5.25	5.75

Rating scale ranged from 1 (prohibited effective, safe mission completion) to 7 (enabled effective, safe mission completion).

Data for a set of objective measures were also collected. These measures included SWAT ratings, Sternberg memory task performance, and a comprehensive set of offensive and defensive performance measures. None of the objective measures showed any significant effects of FOV on performance. The authors suggest that the most likely reason for this result was the difficulty of the flying task regardless of the FOV used.

Silbernagel, B. L. (1982). Using realistic sensor, target, and scene characteristics to develop a target acquisition model. Human Factors, 24(3), 321-328.

This study investigated the effects of display resolution, field of view, target contrast, target range, number of targets, and scene complexity on target detection performance. Photographs were taken of very realistic scenes and were presented individually as slides, rear-projected onto a 30x30 cm ground glass screen. Two line-rate measures of resolution were used, 250 and 525 TV lines. Five other

variables were also manipulated: FOV (6° and 33°), scene complexity (low and high), target number (one and four), target contrast (10 percent and 40 percent), and target range (low and high). Slides were shown individually for a maximum of 30 seconds and time taken to detect the targets was recorded.

Results of an ANOVA indicated that all 6 variables had a significant effect ($p < .05$) on detection time. Increasing resolution from 250 to 525 TV lines reduced target detection times by nearly 50 percent. Mean detection time was reduced 42 percent when subjects viewed low complexity scenes compared to the more complex scenes. Similarly, short-range test images were detected 30 percent faster than long range images. There was a 35 percent reduction in detection time for 4 targets as opposed to 1 target, and there was a 27 percent reduction in detection time with 40 percent target-to-background contrast as compared to 10 percent contrast. Finally, viewing the smaller 6° FOV produced a 32 percent decrease in detection time compared to the 33° FOV. There was also a significant FOV x Range interaction. FOV did not significantly affect detection time at high ranges, but the 6° FOV significantly reduced detection time at short ranges. It should be mentioned that target size was held constant for the different FOVs by reducing the range for the larger visual field.

Generally, the results showed that an increase in display resolution greatly aided in target detection. However, because only two levels of image quality were used, the resolution level above which performance levels no longer increase could not be determined.

Systems Engineering Team: Advanced Avionics Systems Technical Area. (1974). Low level night operations study (Report No. TR-ECOM-4217). Ft. Monmouth, N.J: U.S. Army Electronics Command.

Subjective results of phase 02 of the RAVE flight test results are reported. The purpose of phase 02 was to further define the required display FOV, resolution, and minification for the low-level flight regime. Three subject pilots flew a total of 68 hours. Flights were performed over terrain-avoidance (TA) and terrain-following (TF) courses at low altitudes. Low-level flight was defined as flight less than 175 feet AGL 95 percent of the time. The subject pilot's only flight references were a panel-mounted display and other panel-mounted instruments. The test parameters of the display were FOV (horizontal), resolution, and minification. The experimental values associated with each parameter are listed below in Table 6.

Training flights began at 300 feet AGL with 875-line resolution and a 14-inch screen. The flight profile was lowered and the test parameters degraded as the subject pilot's proficiency increased. After 9.5 hours of training, all three pilots had successfully flown the TA and TF courses at low levels under all conditions of display parameters.

Table 6

Experimental Display Parameters

Parameter		Range
FOV	(degrees)	90° and 80°
Resolution	(lines)	875 and 525
Minification	(screen size)	14 and 8 inches

After a short amount of training, subjects preferred the 8-inch display monitor because of better apparent resolution (at both line rates) and because the compactness of the 8-inch screen reduced the number of required eye movements.

Apparent resolution of either line rate appeared to be better with the 8-inch monitor. Though it was possible to fly the two courses confidently at low level using the 8-inch display and 525-line rate, it was more comfortable to fly using the 875-line rate. With the lower rate, pilots complained that the image appeared gritty and detail was not as clear. In addition, length of eye fixations and number of cross references to other instruments increased with the 525-line rate in comparison to the 875-line rate.

Upton, H. W., & Strothers, D. D. (1972). Design and flight evaluation of a head mounted display and control system. Proceedings of a Symposium on Visually Coupled Systems: Development and Application (pp. 124-143). Brooks Air Force Base, TX: Aerospace Medical Division.

The authors describe an experimental evaluation of an HMD system used for night and instrument flight by helicopter pilots and discuss the human factors problems associated with the system, including visual characteristics of the display.

Low Altitude Flight Study. The first study examined pilots' ability to control the aircraft while using TV imagery presented over the HMD.

Tests were conducted in a Bell 205 equipped with a turret-mounted TV, headtracker, and HMD. The subject's cockpit was completely enclosed. Visual characteristics of the HMD system are listed below.

FOV - 30°
Resolution - 300 raster lines
Shades of Gray - 6
Color - Green phospher
Brightness - 100 fL

Pilots were asked to fly between 75 and 100 feet AGL. Flights were made over a variety of terrain types, including hills, high tension wires, towers, etc.

Those pilots who relied almost totally on the HMD imagery to fly the aircraft performed as well as those who relied totally on their instruments. Pilots were able to fly between 50 and 200 feet while making turns, avoiding obstacles, etc. Pilots expressed a desire for improved image quality, a larger FOV, and flight information to be provided through the HMD.

Stereoscopic Flight Study. The second study used two TV cameras to present the imagery stereoscopically over the HMD. Each TV system had the same performance characteristics listed previously for the monocular system. The results indicated that, in general, stereo viewing was superior to monocular viewing. Subjects expressed a preference for the stereoscopic system and a 1 to 1 magnification ratio with the external scene. The stereoscopic system enabled extended depth perception far beyond the range possible with unaided vision by separating the sensors by distances greater than the pilot's interpupillary distance (IPD). However, the authors suggest that sensor separation closely approximate interocular distance for close viewing tasks such as landing.

Discussion

External Vision - Windshields and Transparencies

Literature that directly investigates external vision requirements for rotary-wing aircraft is very limited. The research that does deal with visual field requirements is focused largely on design specifications for visual display systems rather than windshield requirements. Two issues need to be addressed in this regard. The first task is to determine, experimentally, the absolute minimum amount of external visibility required for successful mission completion. These requirements will vary as a function of flight regime. Obstacle avoidance during nap-of-the-earth (NOE) flight will require more visibility than cruising at high altitudes. Similarly, the performance of air-to-air combat maneuvers will require more visibility than other types of flight regimes. The task of defining visual requirements must involve specifying the typical mission scenarios to be flown by a given aircraft and then specifying the particular tasks that will require the greatest amount of visibility.

The second related task is that of defining the point beyond which further increases in visual field no longer result in performance improvements. Preliminary steps in this direction are described by Martin and Warner (1985). Though their results are based on pilots' subjective ratings, the data suggest that increasing the field of view beyond 90° may not improve performance. Certainly design recommendations should not be made on such preliminary data, but the procedures used in the study represent a step in the right direction for defining such design requirements. By varying the amount of visual field available, either through simulation studies or the collection of in-flight data, the amount of field of view required for various flight tasks could be determined. The second study described by Atkins, Dauber, and Price (1973) collected such in-flight data by masking the amount of available windscreen area. The results indicated that the typical mission profile of the observation helicopter was successfully completed even under the most restrictive masking condition (+10°, -13° forward vision and +10°, -20° side vision). However, the pilots complained that visibility was unsatisfactory and the authors point out that testing occurred under conditions not representative of true-to-life situations.

External Vision - Electro-Optical Systems

Defining the visual requirements of display systems providing external imagery is a rather complex issue. Simply specifying the amount of visual field may not be sufficient. Other interrelated issues must also be considered, including resolution, display optics, sensor slewing capabilities, and characteristics of the human visual system.

In a literature review of helicopter night vision systems conducted by Lazo (1980), it is mentioned that much of the literature treats the issue of resolution as a secondary problem because image quality will be determined by the field of view of the system. An alternative approach is to specify the amount of resolution needed for those tasks requiring the extraction of fine details, and designing a system with the largest

possible field of view which will meet the resolution requirements. After all, a large field of view is not useful if an observer cannot perceive sufficient detail. If there are substantial trade-offs between field of view and resolution, an analysis should be conducted to determine the exact nature of the trade-off in order to quantify it. Performance data should be collected for a variety of tasks to be performed in the field under several different levels of resolution and field of view. Such an evaluation could define a range of acceptable values for the different system parameters to be considered as well as an upper limit beyond which performance reaches an asymptote.

Perhaps an initial step in approaching the problem is to evaluate what is currently available. Army aviators are currently flying at night with the use of night vision goggles and a helmet-mounted display system that provide 40° horizontal fields of view. A comparative analysis might be performed for day flight versus night flight. Those tasks that can be performed during the day but not at night, or can only be performed with limited effectiveness at night, should be identified. Assuming that there are some performance limitations during night flight, an evaluation of the amount of increased vision required to perform these tasks could be undertaken.

An acceptable range of resolution values also needs to be established and, as mentioned previously, should be the first step in defining design requirements. In evaluating resolution, it is important to understand the capabilities and limitations of the human visual system as well as those of the imaging system. The resolving capabilities of the human visual system are greatest for a specific range of spatial frequencies. The Contrast Threshold Function (CTF) defines the contrast threshold of the human visual system as a function of spatial frequency. What the CTF tells us is that there is a minimum level of modulation (contrast) below which the visual system cannot resolve detail. Just as important, the CTF also specifies a maximum spatial frequency above which the visual system no longer detects even the highest possible modulation.

Snyder (1980) provides a thorough discussion of the relationships between the human visual system and imaging systems. The capabilities of the imaging system may be specified in terms of its Modulation Transfer Function (MTF). The MTF of an imaging system relates the amount of modulation output to the amount of modulation input at particular spatial frequencies. Because of inherent limitations of most imaging systems, the amount of output modulation will be somewhat less than the amount of input modulation causing reduction in signal. The amount of reduction may be defined by the following modulation transfer factor ratio:

$$\text{modulation transfer factor} = \frac{M_{out}}{M_{in}} .$$

By plotting the modulation transfer factors across all spatial frequencies, one forms a continuous function, the Modulation Transfer

Function of the system (Snyder, 1980). The MTF describes the changes in modulation that occur when an object is "transferred" to an optical image.

When the CTF of the visual system and the MTF of an imaging system are plotted together as a function of spatial frequency, the result is the Modulation Transfer Function Area, or MTFA (Snyder, 1980). The point at which the two curves cross is the limiting resolution of the imaging system as depicted in Figure 1. This point represents the minimum amount of resolution of the system (defined in spatial frequency terms) that will result in the observer perceiving some amount of detail. Thus, the MTFA specifies the amount of excess signal from the system above the CTF. Of course, for tasks such as detecting complex targets against a cluttered background, the amount of resolution required would be a good bit more than that represented by the CTF. But how much more? Beamon and Snyder (cited in Tannas, 1985) suggest that the area immediately above the CTF is more important than areas well above that point. Said another way, there is some point of maximum resolution above which the resolving capabilities of the visual system begin to level out.

Thus, by using the measures of MTF and CTF, it may be possible to specify a range of acceptable levels of resolution for a number of different tasks. Of course, what is acceptable will depend on the particular performance criteria specified. Greater amounts of resolution will be required for a performance criteria of 95 percent correct target detection, for example, than for a criteria of 50 percent correct. The same specifications will also vary as a function of the particular tasks to be performed. Therefore, it is critical to evaluate the different design parameters in terms of desired performance levels as well as the range of tasks to be performed.

Though there are many different measures of resolution, the MTF is a very useful one because it relates the characteristics of the display system to the characteristics of the human visual system. This is of particular importance from a human factors engineering standpoint. For a detailed description of the use of the MTF, the reader is referred to Snyder, 1980.

Some of the literature reviewed thus far suggests that a resolution range of approximately 525 to 1024 TV lines might be considered for investigation. Silbernagel (1982) presented results which indicated that increasing resolution from 250 to 525 TV lines reduced target detection times by approximately 50 percent. Pilots participating in the Upton and Strothers (1972) study expressed a need for improved image quality using a HMD system providing 300 raster line resolution. Humes and Bauerschmidt (1968) demonstrated 95 percent performance asymptotes after 12 seconds for a target detection task using an imaging system which varied resolution between 524, 729, and 1024 raster lines. However, in a second task presenting smaller and more difficult targets, no asymptote was reached after 22 seconds and increases in resolution produced increases in performance. Results of the latter study again point out the complex interaction between various design variables such as resolution, the specific task to be performed, and performance levels.

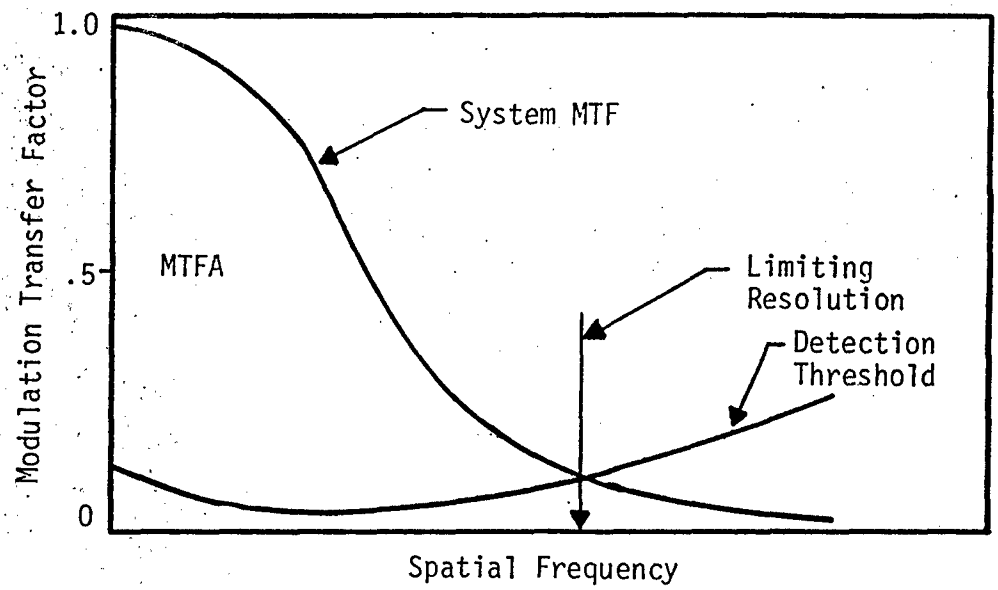

Figure 1. Modulation Transfer Function Area

From Human Visual Performance and Flat Panel Display Image Quality by H.L. Snyder, 1980, p. 336.

Regarding the field of view issue, much of the data reviewed thus far suggest that a FOV of 40° should be considered the minimum for display sensing systems, and that a visual field somewhere on the order of 60° would be preferred. Very little of the research has investigated fields of view greater than 60°. Performance data is needed on a larger range of FOVs in order to determine the point of asymptotic performance.

A logical upper limit on the field of view for such a research effort might be the limits of the human visual system. With the eyes motionless, the average visual field extends to approximately 104° from the central visual axis to the periphery on either side (Bailey, 1982). Though only a small portion of this area provides imagery of relatively good quality, the peripheral areas are very important for motion detection. The detection of anything beyond approximately 104° into the periphery would require head movement. The ability to view beyond this region could be provided by a slewable sensor. Testing might be performed on a range of FOV values between 104° and 40° azimuth to determine the maximum efficient visual field.

Finally, when specifying system FOV, it is important to consider the interactions between FOV and sensor slew actuation. Johnson and Foster (1977) have presented results indicating statistically significant effects of sensor field of view on slew actuation. For narrower FOVs, the amount of slewing increased significantly. This is an important consideration in that requirements for large amounts of sensor slewing will increase pilot workload levels.

Conclusion

Since little research has been conducted to determine external vision requirements and because the specification of display design criteria will vary as a function of task and environmental setting, a series of experimental investigations aimed at providing answers to these very important issues is needed. The following list is a summary of some of the critical issues identified in this literature search that warrant further experimental investigation.

1. Experimentally determine the minimum amounts of external vision required for the various aircraft and their assorted missions.

2. Collect performance data on a large range of FOVs to determine the point of asymptotic performance. Little has been done experimentally with FOVs greater than 60°.

3. Define the tradeoffs between FOV and resolution for imaging devices. A range of acceptable values should be determined for tasks representative of those to be performed in the field.

4. Determine the absolute minimum values of FOV and resolution needed under worst-case situations (e.g., night flight during inclement weather).

5. Experimentally determine the tradeoffs between FOV and sensor slew actuation.

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